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Spatial proximity to others determines how humans inhabit virtual worlds

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ABSTRACT

Highly immersive three-dimensional virtual worlds have emerged as a popular medium for human social interactions. These environments enable multimodal sensory engagement and provide an immersive graphical representation of physical space where users can interact via avatars. However, when compared to two-dimensional virtual settings such as chats, virtual worlds impose constraints on social interactions due to the physical distance between individuals. Using the popular platform of Second Life as a model, we examined how humans manage this interindividual distance in virtual worlds. Taking advantage of methods developed in population ecology, we investigated how avatars are distributed in relation to each other to populate a virtual world. Our results revealed a striking dichotomy in the spatial relationships between avatars. Considerable aggregation, largely independent of population density, was observed alongside surprisingly marked physical isolation. These findings demonstrate that the spatial proximity to others determines how humans inhabit virtual worlds.

1. Introduction

Over the last decade, highly immersive three-dimensional (3D) virtual environments have emerged as a new and popular medium for human social interactions. Many of these virtual worlds have gathered millions of users. For instance, the massively multiplayer online role-playing game (MMORPG) World of Warcraft has reached over 12 million subscribers (Blizzard, 2010) and the virtual world of Second Life has over 20 million registered user accounts (SecondLife, 2011). Compared to simple two-dimensional (2D) text-based platforms, 3D virtual environments offer the possibility of multimodal sensory engagement and provide an immersive graphical representation of physical space where users can interact via "avatars", their embodied representations in virtual space (Cole & Griffiths, 2007; Guitton, 2010; Meadows, 2007; Taylor, 2002). Thus, 3D virtual environments provide a highly realistic space where complex social interactions can take place (Chen, Sun, & Hsieh, 2008; Ducheneaut, Yee, Nickell, & Moore, 2006; Guitton, 2011; Taylor, 2002). However, the dimensional enrichment of virtual space from 2D to 3D also incorporates new constraints on social interactions, namely physical distance between individuals. The aim of this study was to investigate how humans manage interindividual distance in 3D virtual settings. Using the popular virtual world of Second Life as a model, we examined how human-controlled avatars are distributed in relation to each other to populate a virtual world.

The Second Life platform allows users to create 3D avatars through which they navigate an extensive virtual world containing thousands of square regions of fully customizable virtual land (Bainbridge, 2007; Bardzell & Odom, 2008; Guitton, 2011). The freedom of movement is not constrained by rules of game-play, as often observed in other virtual worlds designed for MMORPGs (Alexander, 2003; Bartle, 2003; Chen et al., 2008). Instead, avatars can visit and explore individual regions and freely engage in interactions with other avatars. However, to interact directly, avatars must be in relatively close physical proximity to each other. Interactions typically involve verbal communication, such as text chat or voice, as well as non-verbal gestures or facial expressions. Avatars can also engage in close physical interactions, such as dancing or sexual intimacy (Bardzell & Odom, 2008; Taylor, 2002). Thus, the physical proximity of avatars in the virtual world contributes to the degree and the intimacy of online social engagement that users of Second Life can experience.

To examine how avatars are distributed within the virtual space of Second Life, and in relation to other avatars, we took advantage of mathematical models classically used in population ecology to characterize spatial relationships among individuals (Clark & Evans, 1954; Donnelly, 1978; Sinclair, 1985). We first characterized the population density of randomly selected regions of virtual land. Using the method of nearest neighbor distance (Clark & Evans, 1954), we then examined whether the distribution of avatars within regions of different populations tends to be random, uniform, or aggregated. If distribution is completely random, the

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position of each individual would not be influenced by any other individual, whereas if distribution is uniform or aggregated, the position of each individual would depend on the proximity of others (Clark & Evans, 1954). Finally, we examined the relationship between interindividual proximity and physical distance limits on verbal communication imposed by the Second Life platform. Our results revealed a striking dichotomy in the spatial relationships between avatars. Considerable aggregation was observed alongside marked physical isolation, indicating that the physical proximity of others affects how humans occupy virtual worlds.

2. Methods

2.1. Virtual environment interface

The environment of Second Life (Linden Labs, secondlife.com) is a 3D virtual world subdivided into square regions of virtual land of identical size (256×256 m) that can be accessed by registering and creating an avatar. Two tools of the Second Life interface were used in the present study to examine avatar distribution within the virtual space. The "world map" tool enables users to view and magnify a 2D map of the entire virtual world, and to identify the location and name of each region on the world map and the number of avatars currently present in each region (region population). This tool was used to assess the general density of avatars within the virtual land. The "mini-map" tool, which enables users to determine the specific location of avatars within individual regions of virtual land, was used to ascertain the spatial distribution of avatars in relation to each other. Each avatar is represented on the mini-map by a point and its exact location can be determined by zooming in with viewer controls.

2.2. Avatar density

In order to characterize the general density of avatars within the virtual land of Second Life, the population of 2000 different regions displayed on the world map was recorded on 20 randomly selected occasions over a 4-month period (December 2010 to April 2011, excluding the December Holiday break). For each sampling, 100 individual regions were randomly selected and the number of avatars present in each region was recorded. Different regions were selected on each occasion. The data were collected at randomly selected times of the day.

2.3. Avatar spatial distribution

In order to examine the spatial relationships between avatars, screen shots of mini-maps for randomly selected regions were collected. Because avatars that were very close together often appeared as one dot on the mini-map, actual visualization of all avatars indicated on the mini-map was performed. Since regions are 3D spaces, avatars were sometimes positioned at different vertical levels (e.g., "flying" or occupying a "skybox", which does not allow for direct physical interactions with other avatars in the region). In these cases, only spatial relationships between avatars at the same vertical level were considered. Data collection was performed randomly at various times of day over the same 4-month period as above.

Data from 62 mini-maps of individual regions were collected for a total of 412 avatars. These images were processed using Adobe Photoshop CS3 (Version 10.0, Adobe Systems Inc). The orientation of each mini-map was rotated such that the sides of each square were parallel to the sides of the Photoshop image visualization window. This orientation allowed for the localization of a common XY intercept in the corner of each mini-map. An XY grid was formed starting from this intercept. This allowed for the collection of XY coordinates for each point representing an avatar on each mini-map. The distances between avatars were determined based on their XY coordinates according to the Pythagorean Theorem.

2.4. Nearest neighbor distance

To assess the characteristics of the spatial relationship between avatars, the nearest neighbor distance method was used (Clark & Evans, 1954; Donnelly, 1978; Sinclair, 1985). This approach is commonly used in population ecology and other fields, such as archeology, geography, and cell biology (Sinclair, 1985). It takes into consideration the distance to the nearest neighbor of each individual in an area of a predetermined size and density of individuals. The nearest neighbor distance was calculated for each avatar using the region mini-map data and an overall mean of nearest neighbor distances was generated for regions with the same population. These observed mean nearest neighbor distances were compared to expected values that represented a completely random distribution of individuals for a given population density. In the case of completely random distribution, each observed mean would be roughly equal to the expected value. In the case of aggregated distribution, each observed mean would be lower than the expected value. In the case of uniform distribution (regularly spaced), each observed mean would be higher than the expected value.

The expected value of the nearest neighbor distance was computed according to the equation (Clark & Evans, 1954):

$$E(y) = 0.5\sqrt{A/n} \quad (1)$$

A is the area of the region of interest and n is the number of individuals in the region.

A second computation (corrected nearest neighbor distance) was used in order to account for possible correlations among nearest neighbor distances within a region and edge effects, referring to the tendency of points closer to the boundary of an area to have larger nearest neighbor distances than those inside (Donnelly, 1978). The expected value of the corrected nearest neighbor distance was computed according to the equation (Donnelly, 1978):

$$E(y) = 0.5\sqrt{A/n} + (0.051 + 0.041/\sqrt{n})L/n \quad (2)$$

A is the area of the region of interest, L is the length of the border of the region, and n is the number of individuals in the region.

Both computations were used in the present study to examine whether dependence among nearest neighbor distances and edge effects were indeed relevant contributing factors in assessing the spatial relationships between avatars. Each observed mean was compared to the expected values generated by both of the above equations. The significance of the difference between the observed and expected values was determined statistically.

2.5. Physical distance and limits on communication

The nearest neighbor distance was also considered in relation to the physical limits on communication between avatars. The standard, and most commonly used, mode of communication between nearby avatars in Second Life is text chat. In the standard chat range ("talk"), avatars must be within 20 m of each other to engage in conversation. Users can reduce the range of the chat to "whisper" (range < 10 m), allowing only nearby avatars to detect the chat. Alternatively, users can increase the range to "shout" (range < 100 m) to allow avatars farther away to also detect the chat. Beyond 100 m, direct text chat between avatars is not possible ("out of range"). In the present study, the proportion of avatars within each of the above chat ranges in relation to the nearest neighbor was measured.

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2.6. Statistical analysis

To compare expected values of nearest neighbor distance with observed values, one-sample Student's *t*-tests were performed for each set of regions with a given population of avatars. The normality of each data set was tested using the one-sample Kolmogorov-Smirnov test. Logarithmic transformation was used in cases when normality was violated. The overall proportion of avatars within each of the four chat ranges in relation to the nearest neighbor was compared for regions with a population of 2, 3, 4, and more than 4 avatars using a Chi-square test. Furthermore, the proportions of avatars within chat communication range were calculated for each region with a population of 2, 3, 4, and more than 4 avatars. A non-parametric Kruskal–Wallis test was performed to determine how region population affected the proportion of avatars that fell within communication range in relation to the nearest neighbor. Post-hoc analyses were performed to compare regions with a population of more than 4 avatars to regions with lower populations using Mann–Whitney U tests with a Bonferroni correction for multiple comparisons. Statistical analyses were conducted using SPSS 18.0 (IBM Corp., Somers, NY) with the rejection level set at $p < 0.05$. All data are presented as means ± *SEM*, unless otherwise indicated.

3. Results

3.1. Avatar density

Considerable heterogeneity was observed in the populations of randomly selected regions within the virtual world of Second Life. The total number of avatars present in the 2000 sampled regions was 3350, with individual region populations varying from a minimum of 0 to a maximum of 40 avatars. The vast majority of the avatars (3046 avatars, 91% of the total) shared a region with at least one other avatar, while each of the remaining avatars (304 avatars, 9%) were lone occupants of the region they were located in. When all regions were considered together, the mean population was 1.68 ± 0.09 (Fig. 1). The mean population increased to 3.92 ± 0.18 when only regions with at least 1 avatar were considered, and to 5.54 ± 0.26 when regions with at least 2 avatars were considered. This increase reflected the fact that more than half of the regions polled (57%) contained 0 avatars (Fig. 1, inset). 15% of all regions contained only 1 avatar and only 28% of regions contained 2 or more avatars (10% contained 2 avatars, 5% contained 3 avatars, 3% contained 4 avatars, and 10% contained 4 or more avatars).

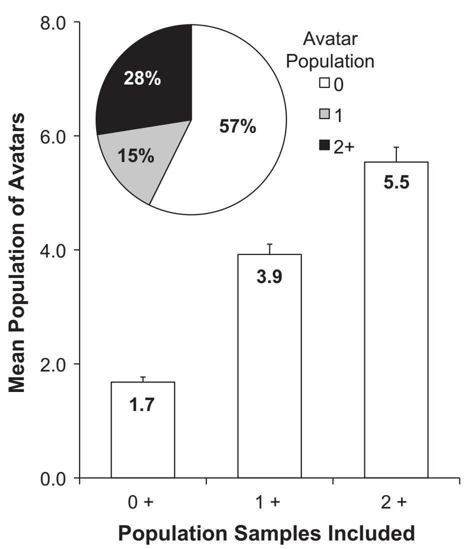

Fig. 1. Population distribution of avatars in standard regions of Second Life's virtual world. Shown is the mean (±*SEM*) population across all sampled regions (0+), in sampled regions with at least one avatar (1+), and in sampled regions containing 2 or more avatars (2+). The inset displays the proportions of the 2000 observed Second Life regions that comprised a population of 0, 1, and 2 or more avatars.

3.2. Avatar spatial distribution

Avatar spatial distribution was analyzed according to a comparison of the expected and observed nearest neighbor distances for regions with populations of 2 and above (Fig. 2). The distribution of nearest neighbor distances violated the assumption of normality for regions with populations of 2, 4, 5, 6, 7, 9, 10, 11, 12, and 15. These distributions were skewed towards lower values, thus a logarithmic transformation was used. Following the transformation, distances for all populations, except for the population of 2, were normally distributed. One-sample t-tests revealed that the observed nearest neighbor distances for these populations were all significantly lower than the expected values computed according to the two models of random distribution ($p < 0.01$ for all tests). This indicates that the spatial distribution of avatars is aggregated rather than random or uniform.

Overall, the mean nearest neighbor distance between avatars followed a biphasic pattern, decreasing exponentially as a function of avatar population for small population sizes (4 avatars or less in a region) and reaching a stable plateau when the population exceeded 5 avatars (Fig. 2). This relationship closely followed an exponential decay function ($R^2 = 0.93$), indicating a rapid decrease in the distance between neighboring avatars towards a constant aggregated state despite relatively low population density.

A more detailed analysis of the spatial relationship between avatars in regions with a population of 2 revealed a bimodal distribution of the distances to the nearest neighbor (Fig. 3). For these regions, approximately half of the avatars were located very close to the nearest neighbor ($M = 3.24$ m, $SEM = 0.77$), whereas the other half of the avatars was located far away ($M = 170.10$ m, $SEM = 10.10$). Because of the bimodal nature of the distribution, these two groups were analyzed separately and compared to the expected values of nearest neighbor distance. Both groups differed significantly from the expected values computed according to the two models of random distribution ($p < 0.01$ for all tests). In one group, nearest neighbor distances revealed aggregation, whereas in the other, distances were farther than would be expected if distribution were random.

3.3. Physical distance and limits on communication

The proportion of avatars within each of the four verbal communication ranges (''whisper'', ''talk'', ''shout'', and ''out of range'') away from the nearest neighbor changed significantly as the population of avatars increased from 2, 3, 4, to more than 4 avatars (Chi-square: c^2 (9, $N = 412$) = 128.73, $p < 0.001$, Fig. 4). The number of avatars within communication range, particularly in the ''whisper'' range, increased, and the number of avatars ''out of range'' substantially decreased. When compared to regions with a population of more than 4 avatars, regions with populations of 2, 3, and 4 avatars had significantly different proportions of avatars across the four chat ranges (Chi-square; 2 avatars: c^2 (3, $N = 354$) = 139.96, $p < 0.001$; 3 avatars: c^2 (3, $N = 358$) = 40.49, $p < 0.001$; 4 avatars: c^2 (3, $N = 356$) = 14.34, $p = 0.002$).

When the proportion of avatars within communication range of their nearest neighbor was considered for each region, there was a significant increase in the proportions of avatars within

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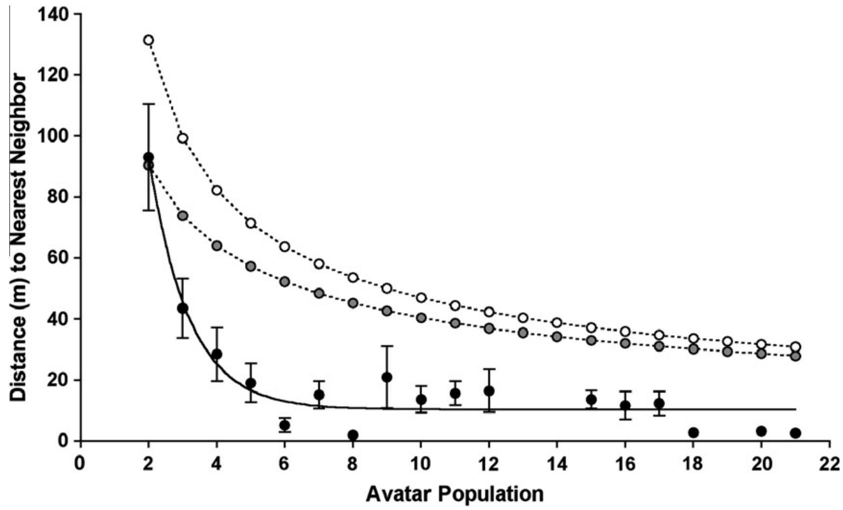

Fig. 2. Mean distance between the nearest neighboring avatars as a function of avatar population. The values for the two theoretical models of expected random distribution, uncorrected (white circles) and corrected (gray circles), are shown alongside observed values (black circles, mean ± *SEM*). Overall, the mean nearest neighbor distance between avatars followed a biphasic pattern, decreasing exponentially as a function of avatar population for small population sizes (4 avatars or less in a region) and reaching a stable plateau when the population exceeded 5 avatars. For all the regions with a population greater than 2, the observed values were significantly lower ($p < 0.01$) than both sets of expected values, indicating a strong tendency towards aggregation.

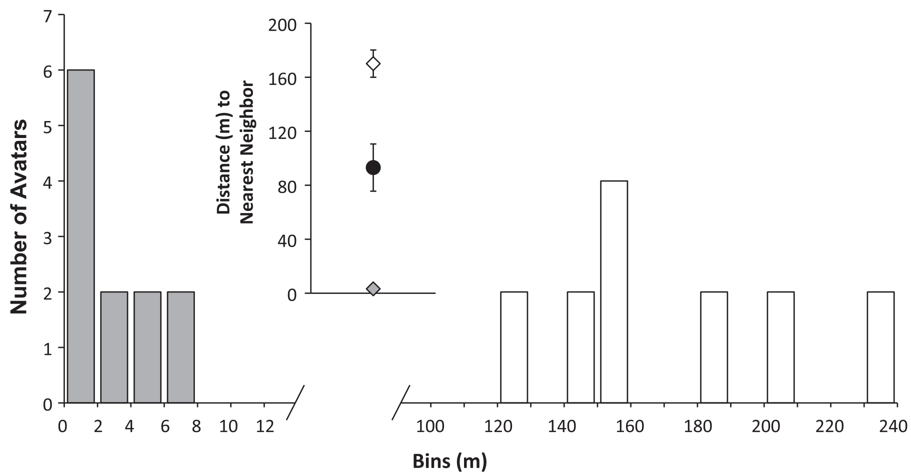

Fig. 3. Bimodal distribution of avatars in regions with a population of 2 avatars. The histogram demonstrates that approximately half of the avatars in these regions were located very close to each other, whereas the other half of the avatars were located far away. The inset shows the mean (±*SEM*) observed nearest neighbor distance for all avatars in regions with a population of 2 (black circle) and the means (±*SEM*) after the bimodal distribution was separated into two groups (white and gray diamonds). Both groups differed significantly from the theoretical values of expected random distribution ($p < 0.01$).

communication range as the region population increased (Kruskal–Wallis: c^2 (3, $N = 62$) = 11.41, $p = 0.01$). Post hoc analyses (Mann–Whitney U-test with Bonferroni correction) revealed a significantly higher proportion of avatars located within communication range for regions with a population of more than 4 avatars compared to regions with 2 avatars, $p = 0.002$ and 3 avatars, $p = 0.04$. As shown in Fig. 4, most avatars within communication range were actually within the ''whisper'' range (77%).

4. Discussion

Although avatars exist in a virtual world, each of them still corresponds to a real human who animates it, imbuing it with a sort of virtual autonomous life. Our results unveiled a striking dichotomy in the way that humans distributed their avatars to occupy the physical space of a 3D virtual world. Using Second Life as a model, we demonstrated that the distribution of avatars in virtual space was not random. When multiple avatars were located in common regions, we observed considerable aggregation that was largely independent of population density. Surprisingly, however, a notable proportion of avatars were also found to be physically isolated from others.

Virtual worlds in general (Alexander, 2003; Bainbridge, 2007; Bartle, 2003; Cole & Griffiths, 2007; Kock, 2008; Lortie & Guitton, 2011), and Second Life in particular (Bardzell & Odom, 2008; Guitton, 2011) are inherently social spaces. Thus, it was expected that avatars would gather together in common regions. Indeed, most avatars (over 90%) were found within regions that contained other avatars. Furthermore, avatars concentrated themselves in a few regions while more than half the total space observed at any given time was unoccupied. However, this tendency to ''be together'' was more striking than expected when the physical aggregation of avatars was assessed by computing the nearest neighbor distance across regions with increasing population density. The physical distance between avatars decreased exponentially as the population density increased, reaching a stable aggregated state once the region population exceeded 5 avatars. However, despite

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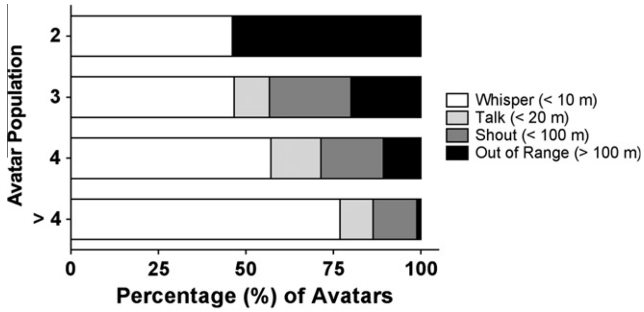

Fig. 4. Proportion of avatars within different communication zones. There was a significant increase in the proportion of avatars within communication range (''whisper'', ''talk'', and ''shout'' zones) as the region population increased from 2 avatars to more than 4 avatars, $p < 0.01$. Given the radius of the different communication zones, a random distribution of avatars would predict that as the avatar population increased, a greater proportion of avatars would be found in the ''shout'' or ''talk'' zones. Instead, most avatars (over 75%) were located so close to another avatar that they were able to communicate through ''whispers''.

this tendency to aggregate, we also observed evidence of physical isolation. At any given time, a fifth of all regions were occupied by only 1 avatar. Furthermore, analysis of regions containing 2 avatars revealed a clear-cut dichotomy in the spatial distribution of avatars. In approximately half of the regions, the 2 avatars were in very close physical proximity to each other (always positioned at a distance that allows physical intimacy and communication using the ''whisper'' mode). This indicates that physical aggregation occurs even at a very low population density. In contrast, in the other half of the regions, the 2 avatars were farther away from each other than would have been expected if distribution were random. Thus, two contradictory behaviors exist in the way that humans position themselves *vis-à-vis* the others in virtual worlds. Aggregation co-exists with isolation.

To understand social behavior at the population level it is important to characterize the spatial relationships between individuals within the available space. In order to assess whether the distribution of avatars in virtual space was random or not, we analyzed our samples according to the classical mathematical models of spatial distribution used in population ecology (Clark & Evans, 1954; Donnelly, 1978; Sinclair, 1985). In the present case, spatial distribution of human-controlled avatars was characterized by an interindividual physical proximity that differed significantly from a random distribution. This applied whether random distribution was estimated using a mathematical model based solely on the density of individuals within a given space (Clark & Evans, 1954) or using a corrected model that takes into account potential correlations among inter-individual distances and ''edge effects'' related to individuals located close to the borders of a sampling area (Donnelly, 1978). Since these mathematical models are based on the proximity of each avatar to its nearest neighbor, aggregation in this case does not necessarily refer to clustering within a single or unique group, but rather the tendency to be close to at least one other individual. However, the high degree of aggregation, especially for regions with a higher population of avatars, indicates that clustering certainly did occur.

The distribution of avatars in relation to the physical space of the virtual world is also important to consider as the design of the environment itself may impact avatar behavior. Certain regions may inherently attract more avatars due to their physical features (Bardzell & Odom, 2008; Guitton, 2011). Others may attract individuals who prefer to explore the virtual world in isolation. Since the maintenance of individual regions in Second Life requires monthly land fees paid by users (Shelton, 2010), it was surprising to find over half of the regions not populated by avatars at any given time. Further studies may take advantage of exploring the potential interaction between social and physical aspects of the virtual world. However, the fact that the physical distribution of avatars is not random within this large and variable virtual space indicates that management of interindividual distance by avatars is not necessarily dependent on the features of the space itself.

Unlike other popular 3D virtual settings such as MMORPGs (Alexander, 2003; Bartle, 2003; Chen et al., 2008), avatars in Second Life can move freely throughout most of the virtual environment. Thus, the choice to aggregate or disperse reflects an active decision making process that is not constrained by game dynamics. Early qualitative work suggests that physical proximity of avatars in virtual worlds translates to particular social intentions, such as friendship, intimacy, or aggression (Becker & Mark, 1999; Taylor, 2002). Even though physical proximity to others is not required for communication in Second Life (e.g., users can communicate through an instant messaging feature that is independent of their location), the 3D rendering of interpersonal distance can enrich the quality of communication and enable users to more easily express their social intentions. Particularly, the multimodal integration of physical features and gestures with verbal communication promotes a more realistic experience in interpersonal interactions. In other words, the physical distance between avatars in the virtual world of Second Life is relevant for the quality and realism of social engagement between users.

The relationship between physical distance and communication is exemplified by our analysis of the location of avatars within different communication zones. As the avatar population increased, the number of avatars within communication range increased significantly, such that over 98% of avatars in regions with a population of 4 or more were within communication range of their nearest neighbor. Given the radius of the different communication zones, a random distribution of avatars would predict that as the avatar density increased, a greater proportion of avatars would be found in the ''shout'' or ''talk'' range, instead of ''out of range''. However, we observed that most avatars (over 75%) were actually located within such a close distance from their neighbors that they were able to communicate through ''whispers''. At this range, any form of verbal as well as non-verbal communication would be detectable among nearest neighbors, enhancing the possibility of developing of a certain degree of interpersonal intimacy (Bardzell & Odom, 2008; Taylor, 2002). Interestingly, being in communication range does not necessarily translate into taking an active role in ongoing social interactions. Indeed, some avatars may remain passive in their interactions with others even if they are nearby (Ducheneaut et al., 2006). Whether physical proximity among avatars reflects a desire for social interaction (Cole & Griffiths, 2007), for seeking an audience (Ducheneaut et al., 2006), or for reassurance in the feeling of togetherness (Bardzell & Odom, 2008; McMillan & Chavis, 1986), the effect is the same: close physical proximity between avatars is a characteristic feature of social interactions in 3D virtual spaces.

Overall, our results highlight the tendency for humans interacting in virtual environments to adjust their spatial location in relation to others, either by isolating themselves, or in the vast majority of cases, by seeking the presence of others. Although traditional communication tools characteristic of 2D virtual settings, such as chats, still exist in the world of Second Life, the 3D virtual setting adds an immersive physical quality to communication. Indeed, interindividual distance between avatars can provide a means of either enabling or avoiding potential social interactions. A better understanding of the nature of human interactions in these 3D virtual environments is critical as they are becoming more popular and more integrated into everyday lives, both for leisure activities and professional use (Bainbridge, 2007; Cole & Griffiths, 2007; Kock, 2008; Mayo, 2009; Murray-Rust, 2008;

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Shelton, 2010). Our findings take a step in this direction by showing that the way humans inhabit a virtual world is not random, but instead it is shaped by the proximity of others.

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References

Alexander, T. (2003). *Massively multiplayer game development*. Hingham, MA: Charles River Media.

Bainbridge, W. S. (2007). The scientific research potential of virtual worlds. *Science, 317*, 472–476.

Bardzell, S., & Odom, W. (2008). The experience of embodied space in virtual worlds: An ethnography of a Second Life community. *Space and Culture, 11*, 239–259.

Bartle, R. (2003). *Designing virtual worlds*. Boston, MA: New Riders Publishing.

Becker, B., & Mark, G. (1999). Constructing social systems through computer-mediated communication. *Virtual Reality, 4*, 60–73.

Blizzard. (2010). World of Warcraft® subscriber base reaches 12 million worldwide. <http://us.blizzard.com/en-us/company/press/pressreleases.html?101007> Retrieved 20.06.11.

Chen, C. H., Sun, C. T., & Hsieh, J. (2008). Player guild dynamics and evolution in massively multiplayer online games. *Cyberpsychology & Behavior, 11*, 293–301.

Clark, P. J., & Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology, 35*, 445–453.

Cole, H., & Griffiths, M. D. (2007). Social interactions in massively multiplayer Online role-playing gamers. *Cyberpsychology & Behavior, 10*, 575–583.

Donnelly, K. (1978). Simulations to determine the variance and edge-effect of total nearest neighbour distance. In I. Hodder (Ed.), *Simulation methods in archaeology* (pp. 91–95). London, UK: Cambridge University Press.

Ducheneaut, N., Yee, N., Nickell, E., & Moore, R.J. (2006). ‘‘Alone together?’’: Exploring the social dynamics of massively multiplayer online games. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*. Montreal, Quebec, Canada: ACM.

Guitton, M. J. (2010). Cross-modal compensation between name and visual aspect in socially active avatars. *Computers in Human Behavior, 26*, 1772–1776.

Guitton, M. J. (2011). Immersive role of non-required social actions in virtual settings: The example of trade role-play in the second life gorean community. *Design Principles and Practices: An International Journal, 5*, 209–220.

Kock, N. (2008). E-collaboration and e-commerce in virtual worlds: The potential of Second Life and World of Warcraft. *International Journal of e-Collaboration, 4*, 1–13.

Lortie, C. L., & Guitton, M. J. (2011). Social organization in virtual settings depends on proximity to human visual aspect. *Computers in Human Behavior, 27*, 1258–1261.

Mayo, M. J. (2009). Video games: a route to large-scale STEM education? *Science, 323*, 79–82.

McMillan, D. W., & Chavis, D. M. (1986). Sense of community – a definition and theory. *Journal of Community Psychology, 14*, 6–23.

Meadows, M. (2007). *I, avatar: the culture and consequences of having a second life*. Thousand Oaks, CA: New Riders Publishing.

Murray-Rust, P. (2008). Chemistry for everyone. *Nature, 451*, 648–651.

SecondLife. (2011). Live Data Feed. <http://wiki.secondlife.com/wiki/Linden_Lab_Official:Live_Data_Feeds> Retrieved 13.06.11.

Shelton, A. K. (2010). Defining the lines between virtual and real world purchases: Second Life sells, but who’s buying? *Computers in Human Behavior, 26*, 1223–1227.

Sinclair, D. F. (1985). On tests of spatial randomness using mean nearest neighbor distance. *Ecology, 66*, 1084–1085.

Taylor, T. L. (2002). Living digitally: Embodiment in virtual worlds. In R. Schroeder (Ed.), *The social life of avatars: Presence and interaction in shared virtual environments* (pp. 40–62). London: Springer-Verlag.

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